

Sülzle, Kai

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Innovation and Adoption of Electronic Business Technologies

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Kai Sülzle

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Innovation and Adoption of Electronic Business Technologies*

Abstract

This paper presents a duopoly model of e-business technology adoption. A leader and a follower benefit from a new e-business technology with uncertain quality depending on its innovation and adoption cost and both firms' adoption timing. When innovation and adoption require large set-up costs, the leader favors quick adoption by the follower. The follower prefers either late or no adoption. This is due to a *delayed* first-mover benefit which stems from an innovators' capability to impose a new technology standard. It is shown that inter-firm adoption subsidies are a viable tool to quicken adoption.

JEL Code: O31, L1.

Keywords: Electronic business, adoption, innovation, network effects.

Kai Sülzle
Ifo Institute for Economic Research
at the University of Munich and
Dresden University of Technology
Poschingerstr. 5
80539 Munich, Germany
Phone: +49(0)89/9224-1282
suelzle@ifo.de

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1 Introduction

The timing and nature of new technology adoption are fundamental issues of firms' business performance. In particular in the last decade, innovation and adoption of electronic business (e-business in the following) technologies, such as procurement platforms or collaborative product development tools played a crucial role as innovative enabler for professional activities and relationships.

The decision to adopt an e-business innovation is an investment decision that involves costs in the expectation of future rather than immediate rewards which are based on efficiency gains in firms' production activities. Since firms are usually in competitive and/or collaborative situations, their gains from an innovation crucially depend on the behavior of other firms.

For example in the automotive industry, large automobile manufacturers and their core suppliers decide on the implementation of electronically enabled tools for collaborative product development, e.g. DaimlerChrysler and Bosch who use collaborative CAD tools for the design and integration of headlight components in cars. Another example for such an e-business technology are procurement platforms as SupplyOn in the automotive industry or click2procure.com by Siemens.¹

Particularly in the innovation and adoption process of e-business technologies, pioneering firms usually receive low returns from technology use as long as they are the single users of the new technology. The reasoning for this observation is twofold: First, technology leaders incur R&D costs in the innovation and implementation phase while the quality of the innovation might still be uncertain. Second, since the innovator of an e-business technology introduces a new technology standard, due to network effects, the earlier other firms adopt the higher might an innovator benefit of an applied technology.

In contrast, followers might not want to adopt quickly since they face lower implementation and adoption costs when they wait longer, i.e. until the quality of the innovation is revealed. Followers might even not adopt at all because they do not want to commit to an external standard developed by another firm.

¹The author and his colleagues have conducted 40 interviews on the usage, adoption and implementation of e-business technologies with CEOs from major industry players to electronic platform providers and suppliers in France, Italy and Germany.

These incentive structures and profit expectations result in two observations: First, new technologies are never adopted by all potential users simultaneously.² Second, the adoption decision crucially depends on the amount of improvement which the new technology offers over any previous technology, its costs of development and implementation and the adoption decision of related firms.

In this context the present paper contributes to the technology adoption literature by accounting for the described peculiarities of e-business technology adoption. In a duopolistic setup we analyze the incentives for innovation and adoption timing of an innovator and an adopter and determine the corresponding cost ranges where the new e-business technology is applied.

Related Literature: While there are many industry-specific and innovation-specific case studies of the adoption of new technologies, the theoretical literature on the adoption of electronic business activities is sparse. Hoppe (2002) and Geroski (2000) provide excellent surveys on both the theoretical literature on new technology adoption and patent races.

Most theoretical contributions have a common base in the seminal work by Reinganum (1981), who provides a duopoly model of technology adoption. In her model a change in market concentration may speed or slow technology adoption if firms make once-and-for-all commitments to their eventual adoption dates. Fudenberg and Tirole (1985) extend this work by studying situations in which firms decide at any point in time whether to adopt a cost-reducing new technology, knowing that adoption costs decline over time. By assumption, the increase in profits due to innovation is greater for the first follower than for the second. This potential first-mover advantage stimulates preemption up to a point where the extra profit flow for the first mover just equals the extra costs of speeding up adoption.

Götz (1993) analyzes the adoption and diffusion of a new technology in a market for a differentiated product with monopolistic competition, showing a positive relationship between firm size and speed of adoption. Additionally, he

²See e.g. Götz (1993).

identifies a rank effect, stating that potential users differ with respect to the (expected) returns from adoption. Further, a stock effect implies a dependency of firms' adoption payoffs on the stock of firms already using a new technology. Such stock effects imply an asymmetry in payoffs of adoptions, which give rise to differing rather than uniform adoption dates in both market and planner solutions.

One of the first contributions dealing with technology adoption in the presence of network externalities was offered Katz and Shapiro (1986). They studied the dynamics of industry evolution in a market with technological change where two inherently incompatible technologies are subject to network externalities. They show that a potential second-mover advantage may result in subgame-perfect equilibria without preemption and payoff equalization. In their model, payoffs to different firms are asymmetric. They further state that in such a setup, network effects are a crucial feature. They dispose over two fundamental effects: first, the relative attractiveness today of rival technologies is influenced by their sales histories: a given product is more attractive the larger is the in-place base of consumers using that product. Second, in the presence of network externalities, a consumer in the market today also cares about the future success of the competing products.

The most related contribution is Benoit (1985), which is based on Jensen (1982), who introduced uncertainty of the profitability of an innovation into the adoption and diffusion literature. In a duopoly model Benoit (1985) derives that a technology leader's expected profits from innovation are not monotonic in the cost of innovation, given that successful innovation is probabilistic. He further shows that an increase in the innovation cost may cause followers to adopt the innovation. In contrast to his contribution we will show that a technology leader profits from early adoption of a follower, while the follower prefers to wait. A viable tool to overcome this discrepancy of interest is the application of inter-firm adoption subsidies.

A similar result where a monopolist may benefit by giving away a technology to a competitor after a time lag, is derived by Farrell and Galliani (1988).

In their model a monopolist benefits from delayed adoption by a competitor because of a price commitment effect on a downstream consumer market. In contrast to the present contribution there is no driving force to induce accelerated adoption due to an inherent network effect in their model.

The remainder of the paper is structured as follows: Section 2 introduces the e-business model. Section 3 analyzes its equilibrium outcome. In section 4 we discuss the possibility of inter-firm innovation cost subsidies as an extension. Section 5 provides a numerical calibration exercise and section 6 concludes the paper.

2 The Model

The basic framework is a modified version of the duopoly model by Benoit (1985), which is adjusted to e-business technology adoption. Consider two risk-neutral and profit maximizing firms using the current best-practice technology which decide upon innovation and adoption of a new e-business technology. The two firms are not necessarily competitors but could also be vertically related players in a value chain or industry. The adoption decision depends on the expected benefits from using the new technology, its implementation cost and the adoption behavior of the other firm.³

The first firm, which will be labeled L as *leader*, has the know-how and resources for the innovation of a new e-business technology. It faces the decision of whether to innovate and implement the new technology or not. When L chooses to develop the new technology, it incurs a fixed cost $C(\geq 0)$ ⁴ and the new technology will be implemented $N(\geq 0)$ periods after the innovation decision.

The second firm is labeled F as *follower*. F gets informed about L 's innovation decision only when the e-business technology is implemented, which is N periods after L 's investment. The follower then has the following possibil-

³Note, this paper focusses exclusively on the costs and benefits associated with the innovation and adoption of a new technology. An analysis of a downstream product or customer market is not an issue.

⁴Although it is theoretically possible that $C < 0$, we do not consider this case since it would not lead to qualitatively different results.

ities of technology adoption: (1) never adopt the new technology; (2) match the new e-business technology immediately at a cost⁵ C with an implementation lag N or (3) decide to wait for K periods until the quality of the new technology is revealed. In this case, F will adopt the new technology only if it is a success and not a failure.⁶ There is no loss of generality through the assumption that L is the first firm to decide upon innovation. If L did not innovate, after some time, F would independently have the same innovation possibilities and hence perform the same calculations as L .

The initial benefit of technology use when both firms apply the old technology is normalized to 0. During any single period in which L has innovated but not (yet) F , the leader earns $\Pi_L(1, X)$ and F earns $\Pi_F(1, X)$. The first argument in brackets shows that only one firm uses the technology. Let X be a random variable that can take one of two values: with probability p it takes the value x_s (for “e-business technology is a success”) and with probability $(1-p)$ it takes the value x_f (for “e-business technology is a failure”). If both firms have implemented the new e-business technology, L earns $\Pi_L(2, X)$ while F earns $\Pi_F(1, X)$.⁷ Both firms are risk-neutral and maximize the expected present values of their profits with the discount rate $\delta \in (0; 1)$.

The relative magnitudes of the respective per period profits from technology usage are supposed to be as specified in the following assumption.

Assumption 1 *The relative magnitudes of the per period profits from electronic business technology usage for both firms are:*

<i>Leader</i>	<i>Follower</i>
$\Pi_L(1, x_s) > \Pi_L(1, x_f)$	$\Pi_F(2, x_s) > \Pi_F(1, x_s)$
$\Pi_L(2, x_s) > 0$	$\Pi_F(2, x_s) > \Pi_F(2, x_f)$
$\Pi_L(1, x_s) < \Pi_L(2, x_s)$	$\Pi_F(1, x_s) \leq \Pi_F(1, x_f)$

⁵We assume that the cost F for technology innovation and adoption are the same for both firms. This could be justified in terms that L has higher costs for product development while F incurs higher implementation costs for staff training for example, since the technology is not produced inhouse.

⁶Obviously, it makes no sense to wait longer than K periods if the new e-business technology is a success. Also, it does not pay to wait any period if a bad innovation will also be matched.

⁷As Benoit (1985) we do not specify the process from which these payoffs arise since there is no need to do so. The only requirement is that this process is relatively stable, so that when innovation and adoption occurs, the situation changes in a predictable way.

Before considering fixed costs, the leader prefers a successful innovation to a failed innovation. Further, L prefers a successful innovation where both firms apply the new technology to no innovation. Due to network effects of e-business technologies, L is better off if both firms use the e-business technology when it is a success than if L is the single user.

If the new e-business technology is a success, F is better off adopting than not matching the new technology (before considering fixed costs). If F also adopts, it is better off when the new technology is a success than a failure. When F does not adopt, it is better off if the innovation is a failure than if it is a success.

Once a firm has implemented the new technology, there is no way to reverse this decision, i.e. the firm stays with the new technology in any case.⁸ It is further assumed that the true quality of the new e-business technology is not revealed immediately after its implementation but $K(\leq N)$ periods after the first firm innovated. Before these K periods, the firms receive no new information on X .

Accordingly, let $\tilde{\Pi}_L(1, X)$ and $\tilde{\Pi}_F(1, X)$ denote the single period profits before the end of the K periods.

By backwards induction, we determine the subgame perfect equilibrium of the game where L decides upon innovation or not and F decides upon its response. In this regard, the leader L has to build an expectation about the follower's response when deciding whether to innovate or not. It is assumed that L correctly assesses F 's beliefs about the innovation of the e-business technology. The notation for present values of the corresponding payoffs are depicted in Table 1 below. We only depict those present values for the case that (at least) L innovates. If no firm innovates and adopts the new technology we assume that both firms use the old technology with a normalized per period profit equal to zero.

⁸This means that the added cost of reversing the investment is prohibitive.

		<i>Follower</i>		
		never adopt	adopt immediately	wait K periods
		V_n^F	V_a^F	V_k^F
<i>Leader</i>	innovate	V_n^L	V_a^L	V_k^L

Table 1: Notation and allocation of present values

The following analysis of the model builds on the mutual best responses of the two firms, based on the respective present values, associated with their decision to innovate and adopt or not. Applying backwards induction, we first analyze the follower's decision problem.

2.1 The Follower's Decision Problem

Given that L innovates and implements the new e-business technology, the follower F has three choices: (1) never adopt the new technology, (2) wait for K periods with the adoption decision adopt, or (3) adopt immediately. In the latter case, F immediately incurs a fixed cost C and the new technology will be implemented after N periods. If F waits for K periods, it can observe whether the innovation is successful or not and then adopts if it is.

2.1.1 Expected present value when F never adopts

If F decides to never respond to an innovation by L , the present value of this strategy is given by:

$$V_n^F \equiv \sum_{i=0}^{K-1} \delta^i E \left[\tilde{\Pi}_F(1, X) \right] + \sum_{i=K}^{\infty} \delta^i E \left[\Pi_F(1, X) \right], \quad (1)$$

where $E[\]$ is the expected value operator. During the first K periods after the implementation of the new e-business technology by L , F receives the expected single period payoff $E \left[\tilde{\Pi}_F(1, X) \right]$ while L uses the new technology alone. After K periods, both firms learn the realization of X , but since F did (and does) not adopt, the follower receives the expected single period payoff $\Pi_F(1, X)$ in every subsequent period.

2.1.2 Present value when F adopts immediately

If F adopts immediately after having noticed that L has innovated (i.e. N periods after L 's innovation decision), F expects the present value:

$$V_a^F \equiv -C + \sum_{i=0}^{K-1} \delta^i E \left[\tilde{\Pi}_F(1, X) \right] + \sum_{i=K}^{N-1} \delta^i E \left[\Pi_F(1, X) \right] + \sum_{i=N}^{\infty} \delta^i E \left[\Pi_F(2, X) \right]. \quad (2)$$

The fixed cost C has to be incurred immediately with the decision to adopt. Again, during the first K periods after the implementation of the new e-business technology by L , F receives the expected single period payoff $E \left[\tilde{\Pi}_F(1, X) \right]$ and L uses the new technology alone. After K periods, both firms learn the type of X , and F receives the expected payoff single period payoff $\Pi_F(1, X)$ until F 's new e-business technology is also implemented (which happens N periods after F 's adoption decision). Afterwards, when both firms apply the new technology, F receives the payoff $\Pi_F(2, X)$ in every period that follows (see Figure 1 for an illustration of the time structure in this case, where t denotes the time periods).

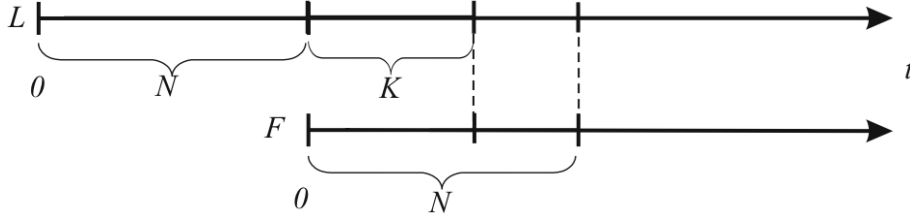


Figure 1: Timing, when F adopts immediately

2.1.3 Present value when F waits K periods till adoption decision

Finally, F can choose to wait K periods (until the type of X is revealed) and then adopt (or not in case that the innovation is a failure). The present value of this strategy is given by:

$$V_k^F \equiv \sum_{i=0}^{K-1} \delta^i E \left[\tilde{\Pi}_F(1, X) \right] + (1-p) \sum_{i=K}^{\infty} \delta^i \Pi_F(1, x_f) + p \left(-\delta^K C + \sum_{i=K}^{N+K-1} \delta^i \Pi_F(1, x_s) + \sum_{i=N+K}^{\infty} \delta^i \Pi_F(2, x_s) \right). \quad (3)$$

Again, F receives the expected single period payoff $E \left[\tilde{\Pi}_F(1, X) \right]$ in the first K periods after the implementation by L . Then, if the new technology is a failure, which happens with probability $(1 - p)$, F does not adopt the new technology and hence receives $\Pi_F(1, x_f)$ in every following period. Otherwise, if the new technology is a success, F chooses to adopt and incurs the present value of the fixed costs F . Further, F receives $\Pi_F(1, x_s)$ as long as the implementation of the new technology did not yet occur. After the implementation F receives $\Pi_F(2, x_s)$ in all future periods (see Figure 2 below).

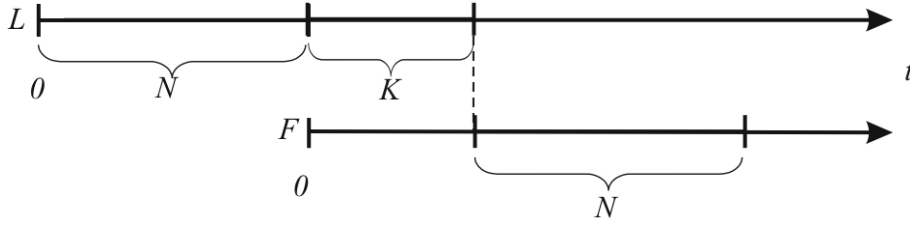


Figure 2: Timing, when F waits for K periods with adoption decision

2.1.4 The follower's adoption choice

The follower's choice depends upon which of the above expressions is the greatest. It will never respond, if:⁹

$$C > \frac{\delta^N}{1 - \delta} \left(\Pi_F(2, x_s) - \Pi_F(1, x_s) \right) \equiv \hat{C} \quad (4)$$

The argument in (4) describes F 's incentive to adopt to a successful innovation. Given that the innovation is successful, F will only adopt if at least the discounted additional per period benefit $\Pi_F(2, x_s) - \Pi_F(1, x_s)$ from new technology usage, which begins N period after F 's potential adoption decision, is higher than its adoption cost C . Otherwise, F will decide to never adopt the new technology. Hence, if (4) does not hold, F will wait K periods, if

⁹See the appendix for a derivation of this relationship.

$V_k^F > V_a^F$ which is the case, when¹⁰

$$\begin{aligned}
(1 - p\delta^K)C &> \frac{\delta^N}{1 - \delta} E \left[\Pi_F(2, X) - \Pi_F(1, X) \right] \\
&\quad - \frac{\delta^{K+N}}{1 - \delta} p \left(\Pi_F(2, x_s) - \Pi_F(1, x_s) \right) \\
&\equiv (1 - p\delta^K)\check{C}.
\end{aligned} \tag{5}$$

Contrarily, if (5) does not hold, the follower prefers to adopt immediately. The following proposition summarizes the follower's choice, which depends on these crucial values of the fixed technology adoption cost C .

Proposition 1 *Ceteris paribus, depending on the fixed adoption cost C , the follower's adoption choice can be specified as follows:*

$$\text{For } C \in \begin{cases} (0, \check{C}], & \text{then } F \text{ adopts immediately,} \\ (\check{C}, \hat{C}], & \text{then } F \text{ waits } K \text{ periods with its adoption decision,} \\ (\hat{C}, \infty], & \text{then } F \text{ never adopts.} \end{cases}$$

Proof. The follower's respective preferences of the three possible actions follow from (4) and (5). It remains to show that $\check{C} \leq \hat{C}$. This holds when

$$E \left[\Pi_F(2, X) - \Pi_F(1, X) \right] \leq \Pi_F(2, x_s) - \Pi_F(1, x_s), \tag{6}$$

which is the case for all $p \in [0; 1]$. ■

The intuition of Proposition 1 is that, all other things remaining unchanged, the higher the fixed adoption cost C , the more likely the follower will either delay its adoption decision until the quality of the new technology is revealed or even not adopt at all.

¹⁰Again, see the appendix for this condition.

2.2 The Leader's Decision Problem

Given the choice by the follower, the leader has to choose between developing and implementing the e-business technology or not. When calculating the respective present values from innovation, L takes into account conditions (4) and (5), so for each of the three possible responses by F , L decides whether to innovate or not.

2.2.1 L 's present value from innovation if F never adopts

If F never adopts, L will innovate, if the present value from innovation V_n^L is positive, yielding

$$V_n^L \equiv -C + \sum_{i=N}^{N+K-1} \delta^i E \left[\tilde{\Pi}_L(1, X) \right] + \sum_{i=N+K}^{\infty} \delta^i E \left[\Pi_L(1, X) \right] > 0. \quad (7)$$

When L innovates and F never adopts, F incurs fixed costs C and receives the expected single period payoff $E \left[\tilde{\Pi}_L(1, X) \right]$ until the type of X is revealed (which happens after $N+K$ periods). Afterwards, L is the only user of the new technology and receives $E \left[\Pi_L(1, X) \right]$ in every subsequent period. Let C_n be the corresponding crucial fixed cost value which determines if the innovation provides a positive present value. From (7) it follows that this is the case if

$$C < \frac{\delta^{N+K}}{1-\delta} E \left[\Pi_L(1, X) \right] + \frac{\delta^N - \delta^{N+K}}{1-\delta} E \left[\tilde{\Pi}_L(1, X) \right] \equiv C_n. \quad (8)$$

If $C < C_n$ then L will innovate if F 's response is to never adopt the new e-business technology.

2.2.2 L 's present value from innovation if F adopts immediately

Given that F chooses the strategy to adopt immediately, L will innovate if $V_a^L > 0$, which reads as

$$\begin{aligned} V_a^L \equiv & -C + \sum_{i=N}^{N+K-1} \delta^i E \left[\tilde{\Pi}_L(1, X) \right] + \sum_{i=N+K}^{2N-1} \delta^i E \left[\Pi_L(1, X) \right] \\ & + \sum_{i=2N}^{\infty} \delta^i E \left[\Pi_L(2, X) \right] > 0 \end{aligned} \quad (9)$$

Again, if L innovates, it incurs fixed costs C . In the time interval between the point in time when the new e-business is implemented and the realization of X is revealed (in $N + K$), the leader receives $E[\tilde{\Pi}_L(1, X)]$ per period. Between the revelation of X and the implementation of the new technology at F , L is the only user of the new technology and hence receives the per period payoff $E[\Pi_L(1, X)]$. Figure 3 shows the timing from L 's perspective.

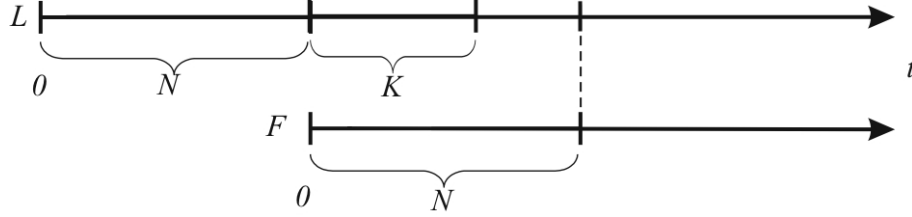


Figure 3: Timing when F adopts immediately

In this case (9) determines the crucial fixed cost threshold value C_a for L 's innovation decision as

$$\begin{aligned}
C &< \frac{\delta^N - \delta^{N+K}}{1 - \delta} E[\tilde{\Pi}_L(1, X)] + \frac{\delta^{N+K} - \delta^{2N}}{1 - \delta} E[\Pi_L(1, X)] \\
&\quad + \frac{\delta^{2N}}{1 - \delta} E[\Pi_L(2, X)] \\
&\equiv C_a.
\end{aligned} \tag{10}$$

If C lies below C_a then L will innovate if F 's response is to adopt immediately after having noticed that F had innovated.

2.2.3 L 's present value from innovation if F waits K periods to adopt

If F chooses to wait K periods till it adopts, L will innovate, if $V_k^L > 0$:

$$\begin{aligned}
V_k^L &\equiv -C + \sum_{i=N}^{N+K-1} \delta^i E[\tilde{\Pi}_L(1, X)] + (1-p) \sum_{i=N+K}^{\infty} \delta^i \Pi_L(1, x_f) \\
&\quad + p \left(\sum_{i=N+K}^{2N+K-1} \delta^i \Pi_L(1, x_s) + \sum_{i=2N+K}^{\infty} \delta^i \Pi_L(2, x_s) \right) > 0.
\end{aligned} \tag{11}$$

The intuition for the payoff till period $N + K$ is identical to the case when F adopts immediately. Since F now waits K periods to decide whether to adopt

or not, F will learn which X -type the technology provides. Accordingly, if X is of type x_f , F will not adopt and therefore L receives the per period payoff $\Pi_L(1, x_f)$ in all future periods. With probability p the new technology is a success. Then F adopts and L subsequently receives the per period payoff $\sum_{i=N+K}^{2N+K-1} \delta^i \Pi_L(1, x_s) + \sum_{i=2N+K}^{\infty} \delta^i \Pi_L(2, x_s)$. (See Figure 4 for a graphical illustration of the timing.) Now, the corresponding crucial fixed cost value C_k

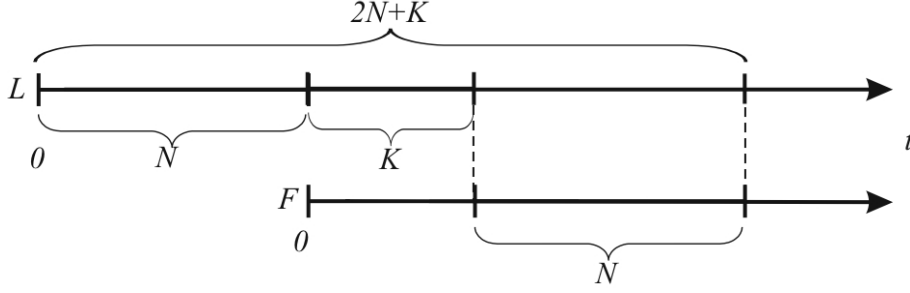


Figure 4: L 's timing when F waits for K periods with its adoption decision

is determined by (11) as

$$C < \frac{\delta^N - \delta^{N+K}}{1 - \delta} E \left[\tilde{\Pi}_L(1, X) \right] + p \frac{\delta^{N+K} - \delta^{2N+K}}{1 - \delta} \Pi_L(1, x_s) + p \frac{\delta^{2N+K}}{1 - \delta} \Pi_L(2, x_s) + (1 - p) \frac{\delta^{N+K}}{1 - \delta} \Pi_L(1, x_f) \equiv C_k. \quad (12)$$

Again, if C lies below this threshold value, L will innovate if F 's response is to wait for K periods.

From the determination of the respective present values from L 's innovation decision, it is easy to see that L is better off when the follower never adopts than when the follower waits K periods, if $V_n^L > V_k^L$, which is the case when

$$\frac{\delta^{N+K}}{1 - \delta} E \left[\Pi_L(1, X) \right] > p \frac{\delta^{N+K} - \delta^{2N+K}}{1 - \delta} \Pi_L(1, x_s) + p \frac{\delta^{2N+K}}{1 - \delta} \Pi_L(2, x_s) + (1 - p) \frac{\delta^{N+K}}{1 - \delta} \Pi_L(1, x_f),$$

which reduces to

$$0 > p \frac{\delta^{2N+K}}{1 - \delta} \left(\Pi_L(2, x_s) - \Pi_L(1, x_s) \right). \quad (13)$$

This inequality never holds since per assumption $\Pi_1(2, x_s) > \Pi_1(1, x_s)$. Obviously, L is better off if the follower plays the strategy of waiting than of never adopting, because a beneficial usage of the new e-business technology requires both firms to apply the new technology.

Accordingly, L prefers F to adopt immediately compared to having F wait for K periods, if $V_a^L > V_k^L$, which holds when

$$0 > p(1 - \delta^K) \left(\Pi_L(1, x_s) - \Pi_L(2, x_s) \right) + (1 - p) \left(\Pi_L(1, x_f) - \Pi_L(2, x_f) \right). \quad (14)$$

From assumption 1 we know that $\Pi_L(1, x_s) < \Pi_L(2, x_s)$. Further, if $\Pi_L(1, x_f) \leq \Pi_L(2, x_f)$ then (14) holds for any $p \in (0; 1]$. Otherwise, if $\Pi_L(1, x_f) > \Pi_L(2, x_f)$ such that L would be worse off if both firms use the new technology when it is a failure than if L were the single user of the new technology, then (14) holds only if

$$p > \frac{\Pi_L(2, x_f) - \Pi_L(1, x_f)}{\left(\Pi_L(1, x_s) - \Pi_L(2, x_s) \right) (1 - \delta^K) + \Pi_L(2, x_f) - \Pi_L(1, x_f)} \equiv J. \quad (15)$$

It is easy to see that $J \in (0; 1)$. Hence, p would have to be sufficiently large so that (14) holds. The assumption that p is sufficiently large can be justified by the intuition that the new e-business technology will only be innovated and implemented if the prospects of success are high. The following proposition summarizes the leader's preferences.

Proposition 2 *Ceteris paribus, for a given C the technology leader's expected present value from innovation is higher when the follower also adopts the new e-business technology, compared to the strategy when the follower never adopts.*

When the probability p for a successful innovation is high, i.e. $p > J$, the leader prefers the follower to adopt immediately. If $p \leq J$ the leader prefers the follower to adopt immediately only if $\Pi_L(1, x_f) \leq \Pi_L(2, x_f)$.

Otherwise, if $\Pi_L(1, x_f) > \Pi_L(2, x_f)$ the leader prefers the adopter to wait with its adoption decision until the type of the new e-business technology is revealed.

Proof. The proof of the first part of Proposition 2 follows from (13) and the second part from (14) and (15). ■

The intuition for the crucial value J is as follows: when the probability for a successful innovation is high, L wants F to follow quickly, since L benefits from the jointly used new technology more than in case of a failure and in case that L is the single user. Practically this could be that F imposes a certain standard of the new technology, which benefits L when F also adopts to this technology, since L would not have any further adjustment cost. When the probability for a successful innovation is low, L prefers F to wait, since the possible beneficial network effect from the joint usage of the new technology vanishes in case of a failure.

3 Equilibrium in the e-Business Model

The above approach completely characterizes the conditions for innovation and adoption, together with the respective resulting benefits from technology usage. In order to determine the resulting equilibrium outcome of the game, the leader's and follower's respective crucial innovation cost values for each of the follower's three adoption options have to be compared. For simplicity, in the following we make the assumption that¹¹

$$\tilde{\Pi}_L(1, X) = \Pi_L(1, X). \quad (16)$$

Accordingly, it follows that (8) now provides

$$C_n = \frac{\delta^N}{1-\delta} E[\Pi_L(1, X)], \quad (17)$$

and (10) reduces to

$$C_a = \frac{\delta^N - \delta^{2N}}{1-\delta} E[\Pi_L(1, X)] + \frac{\delta^{2N}}{1-\delta} E[\Pi_L(2, X)]. \quad (18)$$

Due to (16) and (12), it holds that

$$C_k = \frac{\delta^N}{1-\delta} E[\Pi_L(1, X)] + p \frac{\delta^{2N+K}}{1-\delta} (\Pi_L(2, x_s) - \Pi_L(1, x_s)). \quad (19)$$

From (17), (18) and (19) it follows immediately that $C_k > C_n$ and $C_a > C_n$. The relationship between C_k and C_a depends on p as specified in (15):

¹¹See Benoit (1985) for this assumption.

- For $\Pi_L(1, x_f) < \Pi_L(2, x_f)$, it holds that $C_a > C_k$, whereas
- for $\Pi_L(1, x_f) \geq \Pi_L(2, x_f)$, it holds that $C_a \geq C_k$ if $p \geq J$ and $C_a < C_k$ if $p < J$.

In the context of e-business technology adoption, the relevant case is $\Pi_L(1, x_f) < \Pi_L(2, x_f)$. The intuition is that the leader is worse off if it is the single user of the new technology, compared to the situation when both firms apply the new technology given that it is a failure. This is because if we consider F and L to be participants in an R&D consortium, they cannot interact if one firm (L) uses the new technology and the other firm (F) uses the old technology. When both firms apply the new technology, then there could be some interaction, although it would have been better if both still used the old technology, given that the new technology is a failure.

Therefore, consider the case where $\Pi_L(1, x_f) < \Pi_L(2, x_f)$ such that $C_a > C_k (> C_n)$.¹² The leader's and follower's best responses stem from the comparison of their respective crucial cost values which depend on the relative magnitudes of

$$E\left[\Pi_L(1, X)\right] + p\delta^{N+K}\left(\Pi_L(2, x_s) - \Pi_L(1, x_s)\right) \equiv Q, \quad (20)$$

$$E\left[\Pi_L(1, X)\right] \equiv R, \text{ and} \quad (21)$$

$$\Pi_F(2, x_s) - \Pi_F(1, x_s) \equiv S. \quad (22)$$

Q is the leader's expected single period benefit when the follower waits K periods with its adoption decision. This expected benefit is decomposed into the safe benefit $E\left[\Pi_L(1, X)\right]$ that L receives in every period after the new technology is implemented and a discounted mark-up which L receives only if F adopts after K periods to a successful innovation, which happens with probability p . Accordingly, R is the leader's expected single period benefit when the follower never adopts. S is the follower's gain in its single period benefit from adopting to a successful innovation. It obviously holds that $Q \geq R$ and hence

$$C_k > C_n. \quad (23)$$

¹²The same analysis applies to the case of $\Pi_L(1, x_f) \geq \Pi_L(2, x_f)$ when $p > J$.

Depending upon the specific parameter values, four innovation and adoption patterns can be distinguished: L innovates and F either adopts immediately, waits for K periods or never adopts. Furthermore, a situation where no innovation takes place can be an equilibrium result. The following proposition summarizes these outcomes.

Proposition 3 *Two types of equilibrium outcomes can be distinguished:*

1. *If the new technology is such that L has **more** to gain than F when F adopts a successful innovation, i.e. $Q \geq S$, then*

$$\left. \begin{array}{l} L \text{ innovates and } F \text{ adopts immediately} \\ L \text{ innovates and } F \text{ waits } K \text{ periods} \\ L \text{ innovates and } F \text{ never adopts} \\ \text{no innovation occurs} \end{array} \right\} \text{if } C \in \left\{ \begin{array}{l} (0, \check{C}], \\ (\check{C}, \hat{C}], \\ (\hat{C}, C_n], \text{ for } R > S, \\ (\max\{\hat{C}, C_n\}, \infty). \end{array} \right.$$

2. *Otherwise, if the new technology is such that L has **less** to gain than F when F adopts a successful innovation, i.e. $Q < S$, then*

$$\left. \begin{array}{l} L \text{ innovates and } F \text{ adopts immediately} \\ L \text{ innovates and } F \text{ waits } K \text{ periods} \\ \text{no innovation occurs} \end{array} \right\} \text{if } C \in \left\{ \begin{array}{l} (0, \min\{C_a, \check{C}\}], \\ (\check{C}, C_k], \text{ for } \check{C} < C_k, \\ (\max\{C_k, \min\{C_a, \hat{C}\}\}, \infty). \end{array} \right.$$

Proof. The proof of the first part of Proposition 3 looks at the case when $Q \geq S$. When also $S \geq R$, then it follows that $C_k > \hat{C} > C_n$. The allocation of L 's and F 's respective cost threshold values is then as illustrated in Figure 5 below. Note that in this situation it does not matter whether $C_n \leq \check{C}$ or $C_n < \check{C}$ since $C_n < \hat{C}$ in any case. The resulting equilibrium outcome then depends on the innovation and adoption cost C in the following way:

$$\text{For } C \in \left\{ \begin{array}{ll} (0, \check{C}], & L \text{ innovates, and } F \text{ adopts immediately,} \\ (\check{C}, \hat{C}], & \text{then } L \text{ innovates, and } F \text{ waits } K \text{ periods,} \\ (\hat{C}, \infty], & \text{then no innovation occurs.} \end{array} \right.$$

In this case, F is the crucial player for the determination innovation and adoption occurs or not.

If instead of $S \geq R$ it holds that $S < R$ then $C_k > C_n > \hat{C}$. In this case the

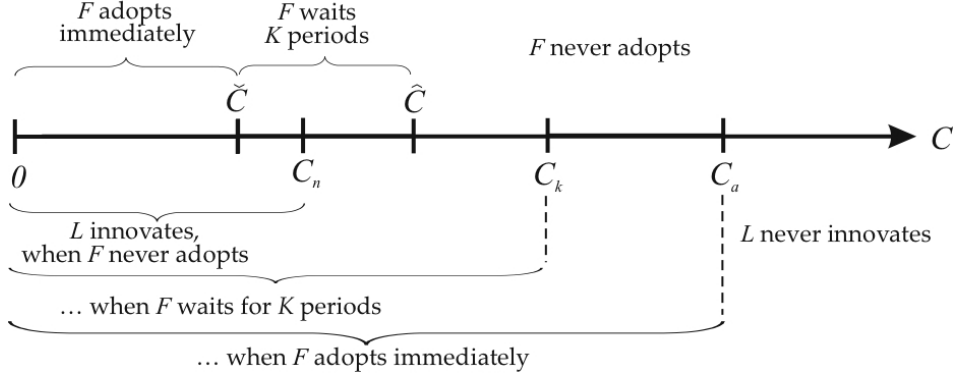


Figure 5: Distribution of crucial C -values for $Q \geq S \geq R$

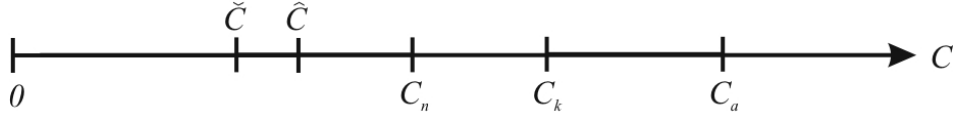


Figure 6: Distribution of crucial C -values for $Q \geq R > S$

crucial threshold values for the innovation and adoption cost are as in Figure 6. Again, L innovates and F adopts immediately, if $C \leq \check{C}$ and L innovates and F waits for K periods with its adoption decision, if $C \in (\check{C}, \hat{C}]$. Now, L can afford to innovate and be the single user of the new technology for C -values in the interval $(\hat{C}; C_n]$. If $C > C_n$, no innovation takes place.

The second part of Proposition 3 considers the case where $S > Q (> R)$, such that $\hat{C} > C_k > C_n$. In this case, two sub-cases with regard to the relative levels of \check{C} and C_k have to be distinguished:

1. When

$$\begin{aligned}
0 &\geq E\left[\Pi_2(2, X) - \Pi_2(1, X)\right] - \delta^K P\left(\Pi_2(2, x_s) - \Pi_2(1, x_s)\right) \\
&\quad - (1 - P\delta^K)\left(E\left[\Pi_1(1, X)\right] - P\delta^{N+K}\left(\Pi_1(1, x_s) - \Pi_1(2, x_s)\right)\right) \\
&\equiv G,
\end{aligned} \tag{24}$$

then it follows that $C_k \geq \check{C}$. Hence it holds that

$$\text{for } C \in \begin{cases} (0, \check{C}], & L \text{ innovates, and } F \text{ adopts immediately,} \\ (\check{C}, C_k], & L \text{ innovates, and } F \text{ waits } K \text{ periods,} \\ (C_k, \infty), & \text{no innovation occurs.} \end{cases}$$

Accordingly, one of the two following graphically illustrated outcomes evolves. Note that there is no qualitative difference in the two potential

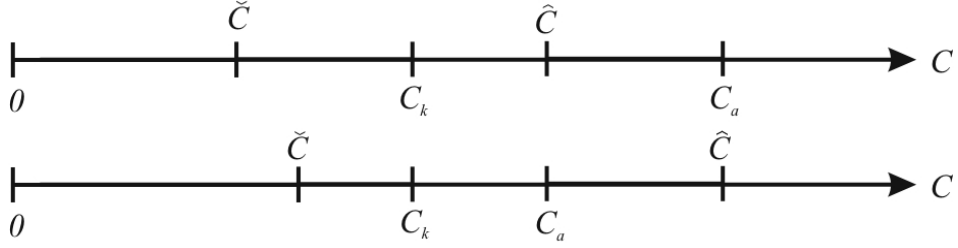


Figure 7: Possible distributions of crucial C -values for $\hat{C} > C_k > \check{C}$

outcomes. Whether $C_a \leq \hat{C}$ depends on whether

$$(1 - \delta^N)E[\Pi_1(1, X)] + \delta^N E[\Pi_1(2, X)] \leq \Pi_2(2, x_s) - \Pi_2(1, x_s). \quad (25)$$

2. Contrarily, when (24) does not hold and therefore $G > 0$, it follows, that $C_k < \check{C}$. In this case, the following equilibrium outcome evolves:

$$\text{For } C \in \begin{cases} (0, \min\{C_a, \check{C}\}] & \text{then } L \text{ innovates, and } F \text{ adopts immediately,} \\ (\min\{C_a, \check{C}\}, \infty] & \text{then no innovation occurs.} \end{cases}$$

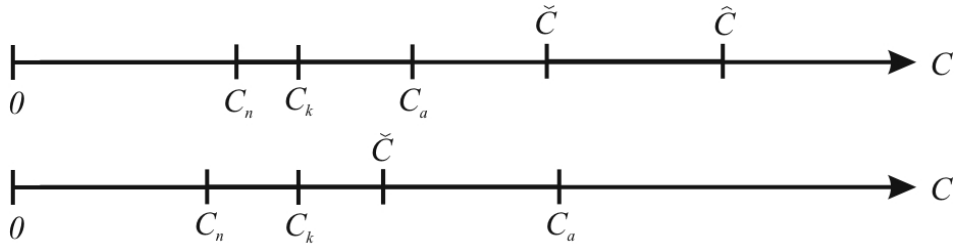


Figure 8: Possible distributions of crucial C -values for $\check{C} > C_k$

The upper threshold cost value for which innovation occurs at least is determined by the minimum of C_a and \check{C} . This minimum is \check{C} , when

$$0 \geq E\left[\Pi_F(2, X) - \Pi_F(1, X)\right] - (1 - \delta^N)E[\Pi_L(1, X)] - \delta^N E[\Pi_L(2, X)] \\ - p\delta^K \left[\Pi_F(2, x_S) - \Pi_F(1, x_S) - E[\Pi_L(1, X)] + \delta^N E[\Pi_L(1, X)] \right. \\ \left. - \delta^N E[\Pi_L(2, X)]\right] \equiv M. \quad (26)$$

Otherwise, if $M > 0$ then $C_a < \check{C}$ and hence innovation only occurs for C -values lower than C_a . Both possible cases are illustrated in the Figure 8 above. ■

The assumptions underlying the outcome in case 2 of Proposition 3 are not very likely to apply for innovation of an e-business technology. This is because usually a pioneering firm counts with higher expected returns from innovation than adopters which is counterintuitive to the case of $S > Q$.

In the more appropriate case for the innovation of an e-business technology as in part 1 of Proposition 3, no innovation occurs for $C > \hat{C}$. The follower's incentive structure is crucial to determining whether innovation occurs or not and whether F immediately adopts or delays the adoption decision. One example for such a delayed adoption is the case of click2procure.com which is a procurement platform provided by Siemens. Initially, this platform was exclusively used by Siemens. Only recently, after some experience on the quality of the new technology, also external corporations use the platform for procurement purposes. Hence, Siemens as innovator now benefits from the adoption of other firms to their technology.

Proposition 4 *With high innovation and adoption costs for the e-business technology and $M < 0$, the followers reluctance to adopt immediately or its general refusal to adopt, hinders innovation.*

Proof. For $Q \geq S$ (which implies $M < 0$), no innovation occurs for $C > \hat{C}$. In this situation L would obviously like to innovate for

$$C \in \begin{cases} (\max\{\hat{C}, C_n\}, C_k], & \text{if } F \text{ would wait } K \text{ periods,} \\ (C_k, C_a], & \text{if } F \text{ would adopt immediately.} \end{cases}$$

For $Q < S$ and $M < 0$, no innovation occurs for $C > \max\{\check{C}, C_k\}$, but L would innovate if F would adopt immediately, for $C \in (\max\{\check{C}, C_k\}, C_a]$. ■

Note that only for $M \geq 0$, and therefore $C_a < \check{C}$, no innovation occurs because L does not innovate, although F would adopt to an innovation. In this case, no innovation occurs for $C > C_a$, but since then $C_a < \check{C}$, the follower would have an incentive to adopt immediately for $C \in \{C_a, \check{C}\}$. As already mentioned above, this scenario is not very appropriate to innovation of an e-business technology.

Hence, the non-adoption decision of the follower prevents the leader from innovating, although the leader would expect positive returns if the follower were to adopt. Such an outcome is typical for an e-business technology innovation decision: due to network effects the more or the earlier other firms adopt, the higher is the benefit of an applied technology to its innovator since the first innovator sets the technology standard. Firms that invest in the development of such technologies impose a new standard and therefore crucially depend on the adoption behavior of customers, suppliers and even competitors. Additionally, pioneering firms usually face lower payoffs from technology use during the time of implementation when they are the only user of the new e-business technology.

4 Extension: Inter-firm Subsidies

The above results show that both firms adopt the new technology only if the e-business innovation and adoption costs C are low enough. When C is higher than the specified threshold values, either no firm innovates and adopts the new technology or just L innovates and F either postpones the adoption decision until the quality of the innovation is revealed or even never adopts. Accordingly, when C is within the ranges specified in Proposition 3, only one firm might have an incentive to innovate or adopt, which results in no innovation. Except in the case of $R > S$, innovation occurs for $C \in (\hat{C}, C_n]$ and L is the single user of the new technology. Otherwise, the lack of adoption hinders innovation. A viable tool to overcome this shortfall is the application

of inter-firm adoption subsidies. Examples for such subsidies are software installation, staff schooling or consulting services. Let β be such an inter-firm payment that reduces its beneficiary's innovation and adoption cost C and increases the corresponding cost of its payer. In order to induce innovation with immediate or delayed innovation, β has to fulfill the following requirements at a given C :

1. The present value from innovation or adoption of the payer of the subsidy β must be weakly higher when the payer's innovation cost C is increased by β than the present value at an innovation cost C .
2. The present value from innovation or adoption of the receiver of the subsidy β must be weakly higher than in the case of not receiving the subsidy. Further, when L subsidizes F then $C - \beta$ must be lower than \check{C} (or \hat{C}) to induce immediate (or delayed) adoption. When F subsidizes L then $C - \beta$ must be lower than C_a (or C_k) to induce innovation with immediate (or delayed) adoption.

Therefore, when firms can subsidize each other, the following result holds.

Proposition 5 *The application of inter-firm adoption subsidies can either enable innovation which otherwise would not have occurred or quicken adoption.*

When $Q \geq S$ then L can benefit from innovating and subsidizing F to induce immediate adoption for $C \in \left(\check{C}, \min\{\check{C} + C_a - C_k, \frac{\check{C} + C_a}{2}\} \right]$ and a delayed adoption decision by F for $C \in \left(\max\left\{ \hat{C}, \min\left\{ \check{C} + C_a - C_k, \frac{\check{C} + C_a}{2} \right\} \right\}, \frac{\hat{C} + C_k}{2} \right]$.

When $Q < S$ and $M \leq 0$, then L can benefit from innovating and subsidizing F to induce immediate adoption for $C \in \left(\check{C}, \min\{\check{C} + C_a - C_k, \frac{\check{C} + C_a}{2}\} \right]$. For $C \in \left(\min\{C_k, \min\left\{ \check{C} + C_a - C_k, \frac{\check{C} + C_a}{2} \right\}, \frac{\hat{C} + C_k}{2} \right]$, F can subsidize L to induce innovation with potential delayed adoption after K periods.

Otherwise, if $M > 0$, F can subsidize L to induce innovation with immediate adoption for $C \in (C_a, \frac{\check{C} + C_a}{2}]$ and innovation with potential delayed adoption for $C \in (\frac{\check{C} + C_a}{2}, \frac{\hat{C} + C_k}{2}]$.

Proof. When $Q \geq S$ then $C_k \geq \hat{C}$ which also implies $C_a > \check{C}$. Accordingly, in a situation where F does not adopt immediately, i.e. $C > \check{C}$, in order to

induce innovation with immediate adoption by the follower, β would have to be such that for the leader it holds that

$$V_a^L(C + \beta) \geq \left\{ \begin{array}{ll} V_k^L(C), & \text{if } C \in (\check{C}, \hat{C}] \\ V_n^L(C), & \text{if } G > 0 \quad \wedge C \in (\hat{C}, C_n] \\ 0, & \text{if } C > \max\{C_n, \hat{C}\} \end{array} \right\} \quad \wedge C + \beta \leq C_a, \quad (27)$$

and for the follower

$$C - \beta \leq \check{C}. \quad (28)$$

It follows a β can fulfill the second part of (27) and (28) only for

$$C \leq \frac{\check{C} + C_a}{2}. \quad (29)$$

With a given C higher than $\frac{\check{C} + C_a}{2}$, L would have to pay such a high subsidy β to induce F 's immediate adoption to an innovation, that $C + \beta$ would be higher than C_a . Hence, this increase in L 's cost due to the high β prevents L from innovating although F would adopt.

From the definition of V_a^L , V_k^L and V_n^L in (7), (9) and (11) it follows that in this case the first part of (27) and (28) only hold for

$$C \leq \check{C} + C_a - C_k. \quad (30)$$

Since both conditions (29) and (30) have to hold simultaneously, the minimum of these two values determines the highest C -value, up to which F can subsidize L to induce innovation with immediate adoption.

When $C > \min\{\check{C} + C_a - C_k, \frac{\check{C} + C_a}{2}\}$ such that L cannot induce immediate adoption by subsidizing F , L can still innovate and achieve that F makes its adoption decision after K periods instead of never adopting. In this case β has to be such that

$$V_k^L(C + \beta) \geq \left\{ \begin{array}{ll} V_n^L(C), & \text{if } G > 0 \quad \wedge C \in (\hat{C}, C_n] \\ 0, & \text{if } C > \max\{C_n, \hat{C}\} \end{array} \right\} \quad \wedge C + \beta \leq C_k. \quad (31)$$

Additionally, for the follower it must hold

$$C - \beta \leq \hat{C}. \quad (32)$$

Due a similar argumentation as above, this is only possible for

$$C \leq \frac{\hat{C} + C_k}{2}. \quad (33)$$

The second part of Proposition 5 considers the case $Q < S$ implying $C_k < \hat{C}$. Hence, L might only induce immediate but not delayed adoption through a subsidy. This happens for $M \geq 0$, under the same conditions as derived above for the case of $Q \geq S$. Further, when $M \geq 0$ then a subsidy from F to L could induce innovation with potential delayed adoption. In this case β would have to be such that

$$C - \beta \leq C_k \quad \wedge \quad C + \beta \leq \hat{C}. \quad (34)$$

Obviously, those conditions only hold simultaneously for $C < \frac{\hat{C} + C_k}{2}$ so that for $C \in (C_k, \frac{\hat{C} + C_k}{2}]$, F can subsidize L to induce innovation with potential delayed adoption after K periods.¹³

Finally, when $M < 0$, it holds that $C_a < \check{C}$ such that only F can apply an innovation subsidy to L to induce innovation, when $C > C_a$. To induce innovation with immediate adoption, β would have to be such that

$$C + \beta \leq \check{C} \quad \wedge \quad C - \beta \leq C_a. \quad (35)$$

To induce innovation with a delayed adoption decision, β would have to be such that

$$C + \beta \leq \hat{C} \quad \wedge \quad C - \beta \leq C_k. \quad (36)$$

The conditions under which those respective requirements hold are specified above. Hence, now F pays the subsidy to induce innovation for a C in the specified ranges as in the last part of Proposition 5. ■

As determined in Proposition 2, L prefers F to adopt quickly rather than to wait with its adoption decision or even not to adopt at all. This is due

¹³Note, that in this case, if $C_k < \min\{\check{C} + C_a - C_k, \frac{\check{C} + C_a}{2}\}$, L could adopt F to induce immediate adoption an F could subsidize L to induce innovation with delayed adoption, for $C \in (\min\{\check{C} + C_a - C_k, \frac{\check{C} + C_a}{2}\}, \frac{\hat{C} + C_k}{2}]$. Both firms prefer the case when L subsidizes F .

to the standard setting capability of a pioneering firm, which implies a positive network effect that benefits L when F adopts to its standard. For high C -values the payment of an inter-firm adoption subsidy is a viable tool to enable or at least quicken innovation and adoption, that would otherwise not have happened. Therefore, in e-business relationships, pioneering firms often sponsor or subsidize the adoption by suppliers, customers and even competitors in terms of staff training, consulting or even financial support for new hard- and software investments. Such a situation corresponds to the first part of Proposition 5. But also the other case as described in the second part of Proposition 5, where followers pay subsidies to pioneering firms are observable in the e-business practice. For example in customer-supplier relationships, the introduction of electronic procurement platforms by large companies such as Siemens with click2procure.com put high pressure on its suppliers. Therefore suppliers had to adopt to the new standard since otherwise they would have lost the customer. Besides the application of explicit registration fees, such an implicit cost can also be interpreted as a type of subsidy. The present paper does not specify the decision process that determines which player pays the subsidy and how big it is. Accordingly, the outcome of the second part of Proposition 5 does not imply that F necessarily induces the payment. It could also be that L offers F a contract that commits F to make a payment as in the mentioned examples.

5 Calibration Exercise

In order to shed some light on the rather technical approach above, consider the following numerical example. Many different combinations of parameter values are possible under the setup in Assumption 1. The following calibration exercise provides an example for each of the two equilibrium types of $Q \geq S$ and $Q < S$, as derived in Proposition 3.

Scenario 1

Assume that the respective magnitudes of the per period profits from electronic business technology usage for both firms take the following values:

<i>Leader</i>	<i>Follower</i>
$\Pi_L(1, x_s) = 0.500$	$\Pi_F(1, x_s) = 0.000$
$\Pi_L(1, x_f) = -0.800$	$\Pi_F(1, x_f) = 0.100$
$\Pi_L(2, x_s) = 2.000$	$\Pi_F(2, x_s) = 0.300$
$\Pi_L(2, x_f) = -0.500$	$\Pi_F(2, x_f) = -0.200$

Note that the assumption of a positive $\Pi_F(1, x_f)$ could be justified by the intuition that the follower gets a small positive benefit when it does not match a failed innovation. This could be interpreted as an ideological benefit from not making the same “mistake” as the leader or by thinking of an expectation of any future advantage when the follower possibly introduces a new technology and hence builds on the experience from having a bad example in terms of the leader’s failed innovation.

Certainly, if we think of an old technology that already disposes of some network effects, then $\Pi_F(1, x_f)$ and $\Pi_F(1, x_s)$ would have to be negative. Since the per period benefits when both firms use the old technology is normalized to zero, the present model does not consider this option.

Given the per period benefits from above, we get the calculated values:

$E[\Pi_L(1, X)] = 0.240$	$Q = 0.396$	$C_n = 0.130$
$E[\Pi_L(2, X)] = 1.500$	$R = 0.240$	$C_a = 0.277$
$E[\Pi_F(1, X)] = 0.020$	$S = 0.300$	$C_k = 0.214$
$E[\Pi_F(2, X)] = 0.200$	$M = -0.230$	$\check{C} = 0.037$
	$G = -0.170$	$\hat{C} = 0.162$

Since $Q > S > R$, it holds that $C_k > \hat{C} > C_n$ such that this scenario is an example for the first part of Proposition 3. The corresponding alignment of the crucial values for C is as depicted in Figure 5 above.

The equilibrium outcome is then as follows: For $C < \check{C} = 0.037$ innovation with immediate adoption occurs. For $C \in (\check{C} = 0.037, \hat{C} = 0.162]$ L innovates and F waits for K periods with its adoption decision. This is because $Q > S$, which implies $C_k > \hat{C}$. For $C > \hat{C} = 0.162$, no innovation occurs because of $S > R$ and therefore $C_n < \hat{C}$.

Figure 9 plots the corresponding present values (PVs) for different C -values, given the per period benefits from technology usage as in Scenario 1. See the appendix for the underlying data table. The straight lines show the

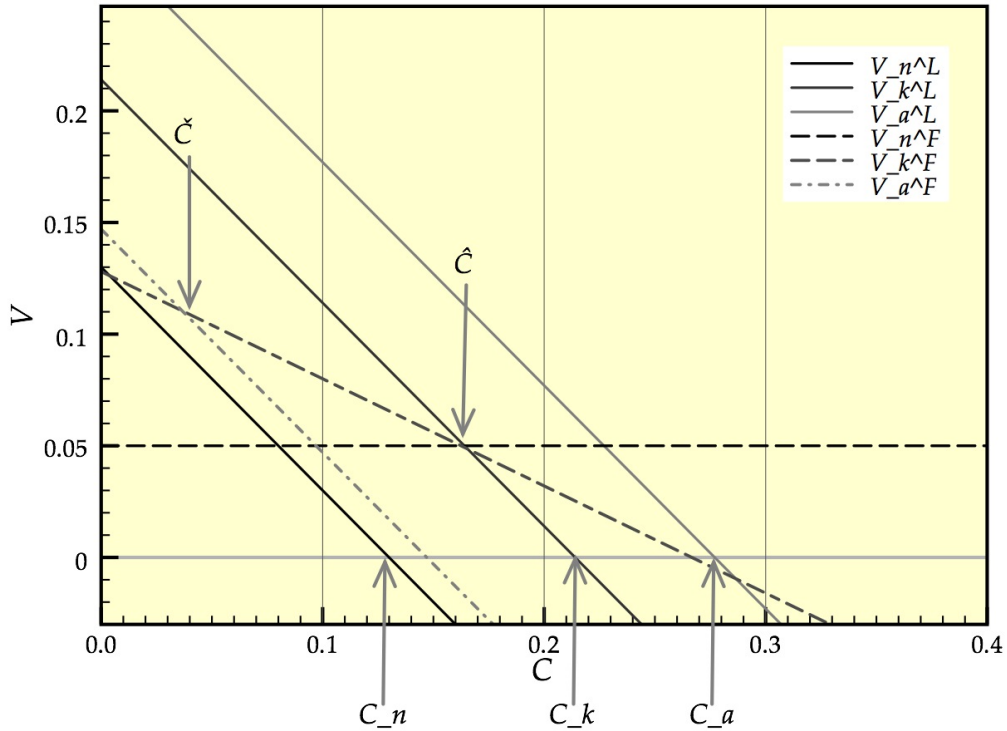


Figure 9: Present values for the case $Q > S > R$ as in Scenario 1

leader's expected present values from innovation and the dotted lines are the follower's respective expected values from adoption. The result from Proposi-

tion 2 that for any given C the leader prefers immediate adoption to delayed adoption and delayed adoption to no adoption is obvious. Furthermore, in the cost-intervall $(0, \check{C}]$, immediate adoption provides the highest expected present value for F . From the intersection of V_a^F and V_k^F at \check{C} until \hat{C} , the best option for F is to wait for K periods with its adoption decision. For higher C -values than \hat{C} , no adoption is best for F . Since there is no uncertainty associated with the decision to never adopt, V_n^F is constant.

The intersections of the zero line with L 's expected present values from innovation, given the three choices by F , determine the leaders crucial values C_n , C_k and C_a , respectively.

As stated in Proposition 5, adoption subsidies could induce earlier innovation. Given the exemplary numbers, L could innovate and subsidize F 's immediate adoption for $C \in \left(\check{C}, \check{C} + C_a - C_k \right] = (0.037, 0.100]$ since $\frac{\check{C} + C_a}{2} = 0.157 > \check{C} + C_a - C_k = 0.100$. Due to $\hat{C} = 0.162 > \check{C} + C_a - C_k = 0.100$, L could subsidize F for $C \in \left(\hat{C}, \frac{\hat{C} + C_k}{2} \right] = (0.162, 0.188]$, to enable innovation with potential delayed adoption by F .

Such a subsidy could work as follows:

- Consider innovation and adoption costs $C' = 0.050$. With such costs, L innovates and F waits for K periods, providing $V_k^L(C') = 0.164$ and $V_k^F(C') = 0.104$, respectively.¹⁴

L could subsidize F with a $\beta = 0.025$ such that F 's adoption cost would be reduced to $C' - \beta = 0.050 - 0.025 = 0.025$ which is lower than $\check{C} = 0.037$. Accordingly, L 's innovation costs increase to $C' + \beta = 0.075$, which is still lower than $\check{C} + C_a - C_k = 0.100$.

After the application of the subsidy, innovation with immediate adoption occurs, providing $V_a^L(C' + \beta) = 0.202 > V_k^L(C') = 0.164$ and $V_a^F(C' - \beta) = 0.122 > V_k^F(C') = 0.104$. Hence, the application of the subsidy quickens adoption as derived in Proposition 5.

¹⁴See the appendix for the calculated data.

- Consider innovation and adoption costs $C'' = 0.175$. At this costs, no innovation occurs, because $C'' > \hat{C}$, providing benefits equal to 0 for both firms.

Here, L could subsidize F with a $\beta = 0.010$ such that F 's adoption cost would be reduced to $C'' - \beta = 0.170 - 0.010 = 0.160$ which is lower than $\hat{C} = 0.162$. L 's innovation costs increase to $C'' + \beta = 0.180$, which is lower than $\frac{\hat{C} + C_k}{2} = 0.188$.

Applying the subsidy enables innovation with a delayed adoption decision by F , providing $V_k^L(C'' + \beta) = 0.034 > 0$ and $V_k^F(C'' - \beta) = 0.051 > 0$. Hence, both firms are better off with the subsidy which enables innovation.

Scenario 2

Now that $\Pi_F(2, x_s) = 0.800$ (instead of 0.300 as in Scenario 1), while all other things remain unchanged as in Scenario 1. Accordingly, we now get the following calculated values:

$E[\Pi_L(1, X)] =$	0.240	$Q =$	0.396	$C_n =$	0.130
$E[\Pi_L(2, X)] =$	1.500	$R =$	0.240	$C_a =$	0.277
$E[\Pi_F(1, X)] =$	0.020	$S =$	0.800	$C_k =$	0.214
$E[\Pi_F(2, X)] =$	0.600	$M =$	-0.070	$\check{C} =$	0.204
		$G =$	-0.010	$\hat{C} =$	0.432

Obviously, $S > Q > R$ and therefore $\hat{C} > C_k > C_n$ so that this is an example for the second part of Proposition 3 (and also 5).

Now, the following equilibrium outcome evolves: for $C < \check{C}$ L innovates and F adopts immediately; for $C \in (\check{C}, C_k]$ L innovates and F waits for K periods to decide whether to adopt or not; for $C > C_k$ no innovation occurs. The corresponding present values are plotted in Figure 10.¹⁵ Following Proposition 5, for $C \in (\check{C}, \min\{\check{C} + C_a - C_k, \frac{\check{C} + C_a}{2}\}]$ L could subsidize F to

¹⁵The description of the crucial values in the plot follows the intuition as in Scenario 1 and is selfexplaining. See the data table in the appendix.

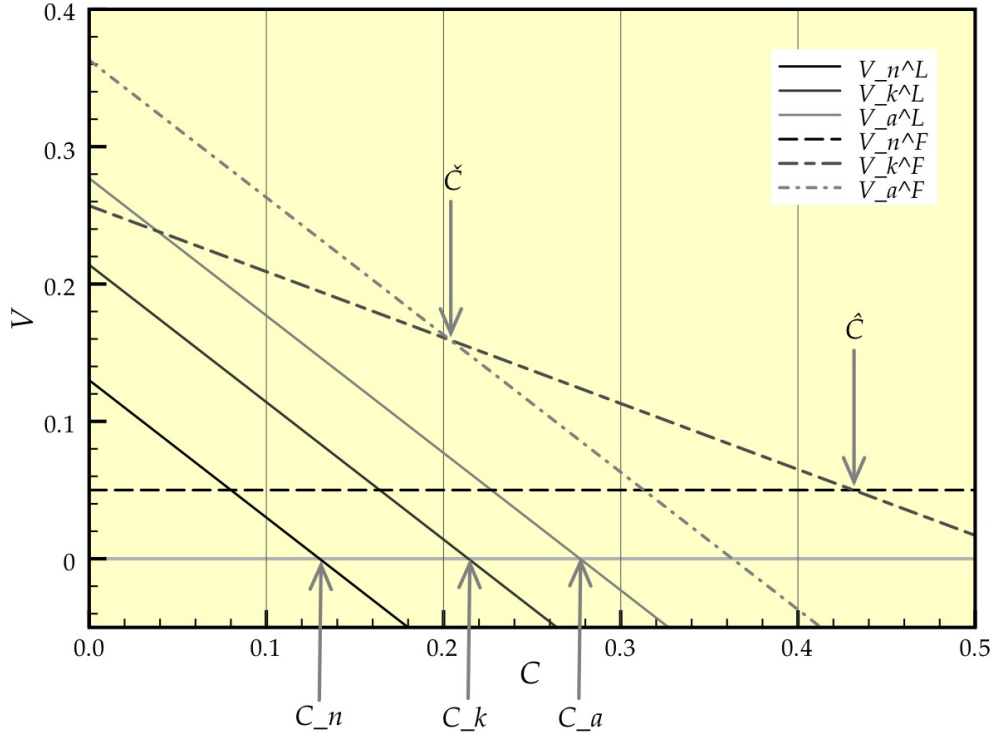


Figure 10: Possible distributions of C -values for the case $\hat{C} > \check{C} > C_k$

induce innovation with immediate adoption. Since $\check{C} + C_a - C_k = 0.267 > \frac{\check{C} + C_a}{2} = 0.240$, this applies for $C \in (0.204, 0.240]$. Following the argumentation as in Scenario 1 above, the exemplary values $C = 0.230$ and $\beta = 0.030$ provide such an outcome.

For $C \in \left(\min\{C_k, \min\{\check{C} + C_a - C_k, \frac{\check{C} + C_a}{2}\}, \frac{\hat{C} + C_k}{2} \right] = (0.240, 0.323]$, a subsidy from F to L enables innovation with a delayed adoption decision. Take a given $C = 0.260$ and the subsidy $\beta = 0.050$, for example.

6 Conclusion

The present paper accounts for the specifics of the innovation and adoption process of electronic business technologies that are determined by the amount of fixed costs for development and implementation of a new technology. When the adoption of an e-business technology requires large set-up costs, a firm's decision to adopt or not depends on the comparison of gains and losses, associated with the use and installation of the new technology.¹⁶

Particularly in the adoption process of e-business technologies, followers benefit from late adoption since they face lower R&D costs for the development of an e-business software, for example. Due to this peculiarity, pioneering firms usually face lower payoffs from technology use during the time of implementation. Further, such leaders in e-business adoption scenarios usually have lower benefits from technology usage when they are the only user of a new e-business technology. This is due to network effects, the more or the earlier other firms adopt, the higher is the benefit of an applied technology to its innovator due to the fact that the first innovator sets the technology standard. An additional focus of the analysis is on the commonly observable subsidization activities of firms that develop and apply e-business technologies, because they benefit indirectly from the adoption of related business partners, as in a customer supplier relationship, for example.

The current model could be extended in various ways: one obvious extension could be the analysis in an oligopolistic setup instead of the 2-firm case. Nonetheless, the results deduced above contain some predictive power for such a scenario as well. An innovator of a new technology would still have standard setting capacities associated with fixed development costs. But in an oligopolistic scenario, it could be the case that the network effect that results from an increase in the number of adopting firms somehow has an upper ceiling in terms of the total number of followers if we think of potential network congestion in terms of administrative and service costs.

Another interesting extension would be to endogenously determine the

¹⁶See Chen (1996).

number of periods the follower would optimally choose to adopt as well as the optimal number of periods the leader would want the follower to follow. Obviously, this extension would require some notational clarification of the interpretation of the parameter K . In the present setup, K determines the time till the true value of the innovation is revealed and simultaneously the time the follower would wait in case that it doesn't immediately adopt. This extension will be taken up in future research.

Appendix

Derivation of condition (4)

In order to determine which decision delivers the highest expected payoff, we compare the three options. The follower is better off never adopting to the new technology, compared to immediately adopting, if $V_n^F > V_a^F$. That is:

$$\begin{aligned}
\sum_{i=0}^{K-1} \delta^i E \left[\tilde{\Pi}_F(1, X) \right] + \sum_{i=K}^{\infty} \delta^i E \left[\Pi_F(1, X) \right] &> -C + \sum_{i=0}^{K-1} \delta^i E \left[\tilde{\Pi}_F(1, X) \right] \\
&+ \sum_{i=K}^{N-1} \delta^i E \left[\Pi_F(1, X) \right] \\
&+ \sum_{i=N}^{\infty} \delta^i E \left[\Pi_F(2, X) \right] \\
C &> \frac{\delta^N}{1-\delta} \left(E \left[\Pi_F(2, X) \right] - E \left[\Pi_F(1, X) \right] \right)
\end{aligned} \tag{37}$$

Accordingly, F is better off to never adopt compared to wait for K periods, iff $V_n^F > V_k^F$. Since $\sum_{i=0}^{K-1} \delta^i E \left[\tilde{\Pi}_F(1, X) \right]$ evolves in both terms, this reads as:

$$\begin{aligned}
\sum_{i=K}^{\infty} \delta^i E \left[\Pi_2(1, X) \right] &> p \left(-\delta^K C + \sum_{i=K}^{N+K-1} \delta^i \Pi_2(1, x_s) + \sum_{i=N+K}^{\infty} \delta^i \Pi_2(2, x_s) \right) \\
&+ (1-p) \sum_{i=K}^{\infty} \delta^i \Pi_2(1, x_f)
\end{aligned}$$

Since $\sum_{i=K}^{\infty} \delta^i E[\Pi_2(1, X)] = \sum_{i=K}^{\infty} \delta^i \Pi_2(1, x_s) + (1-p) \sum_{i=K}^{\infty} \delta^i \Pi_2(1, x_f)$, this reduces to

$$\begin{aligned} \delta^K C &> \sum_{i=N+K}^{\infty} \delta^i \Pi_2(2, x_s) - \sum_{i=N+K}^{\infty} \delta^i \Pi_2(1, x_s) \\ C &> \frac{\delta^N}{1-\delta} (\Pi_2(2, x_s) - \Pi_2(1, x_s)) \equiv \hat{C} \end{aligned} \quad (38)$$

Derivation of condition (5)

Given that it is not a best response to never adopt the new e-business technology, i.e. (4) does not hold, F compares the two options of waiting for K periods until the quality of the innovation is revealed and of adopting immediately. Accordingly, F prefers to wait, if $V_k^2 > V_a^2$, which is

$$\begin{aligned} p \left(-\delta^K F + \sum_{i=K}^{N+K-1} \delta^i \Pi_2(1, x_s) + \sum_{i=N+K}^{\infty} \delta^i \Pi_2(2, x_s) \right) &> -F + \sum_{i=N}^{\infty} \delta^i E[\Pi_2(2, X)] \\ &+ (1-p) \sum_{i=K}^{\infty} \delta^i \Pi_2(1, x_f) \quad + \sum_{i=K}^{N-1} \delta^i E[\Pi_F(1, X)] \end{aligned}$$

Again, since $\sum_{i=K}^{\infty} \delta^i E[\Pi_2(1, X)] = \sum_{i=K}^{\infty} \delta^i \Pi_2(1, x_s) + (1-p) \sum_{i=K}^{\infty} \delta^i \Pi_2(1, x_f)$, this reduces to

$$\begin{aligned} (1-p\delta^K)F + \sum_{i=N+K}^{\infty} p(\delta^i \Pi_2(2, x_s) - \delta^i \Pi_2(1, x_s)) &> \sum_{i=N}^{\infty} \delta^i E[\Pi_2(2, X) - \Pi_F(1, X)] \\ (1-p\delta^K)F &> \frac{\delta^N}{1-\delta} E[\Pi_2(2, X) - \Pi_F(1, X)] \\ &- \frac{\delta^{K+N}}{1-\delta} p(\Pi_2(2, x_s) - \Pi_2(1, x_s)). \end{aligned} \quad (39)$$

which is the outcome of (5).

Data tables for the calibration exercise

Scenario 1 - Data table

C	V_n^L	V_k^L	V_a^L	V_n^F	V_k^F	V_a^F
0.00	0.130	0.214	0.277	0.050	0.128	0.147
0.05	0.080	0.164	0.227	0.050	0.104	0.097
0.10	0.030	0.114	0.177	0.050	0.080	0.047
0.15	-0.020	0.064	0.127	0.050	0.056	-0.003
0.20	-0.070	0.014	0.077	0.050	0.032	-0.053
0.25	-0.120	-0.036	0.027	0.050	0.008	-0.103
0.30	-0.170	-0.086	-0.023	0.050	-0.016	-0.153
0.35	-0.220	-0.136	-0.073	0.050	-0.040	-0.203
0.40	-0.270	-0.186	-0.123	0.050	-0.064	-0.253
0.45	-0.320	-0.236	-0.173	0.050	-0.088	-0.303
0.50	-0.370	-0.286	-0.223	0.050	-0.112	-0.353
0.55	-0.420	-0.336	-0.273	0.050	-0.136	-0.403
0.60	-0.470	-0.386	-0.323	0.050	-0.160	-0.453

Table 1: Expected present values with variable C for $Q \geq S \geq R$

Scenario 2 - Data table

C	V_n^L	V_k^L	V_a^L	V_n^F	V_k^F	V_a^F
0.00	0.130	0.214	0.277	0.050	0.257	0.363
0.05	0.080	0.164	0.227	0.051	0.233	0.313
0.10	0.030	0.114	0.177	0.052	0.209	0.263
0.15	-0.020	0.064	0.127	0.053	0.185	0.213
0.20	-0.070	0.014	0.077	0.054	0.161	0.163
0.25	-0.120	-0.036	0.027	0.055	0.137	0.113
0.30	-0.170	-0.086	-0.023	0.056	0.113	0.063
0.35	-0.220	-0.136	-0.073	0.057	0.089	0.013
0.40	-0.270	-0.186	-0.123	0.058	0.065	-0.037
0.45	-0.320	-0.236	-0.173	0.059	0.041	-0.087
0.50	-0.370	-0.286	-0.223	0.060	0.017	-0.137
0.55	-0.420	-0.336	-0.273	0.061	-0.007	-0.187
0.60	-0.470	-0.386	-0.323	0.062	-0.031	-0.237

Table 2: Expected present values with variable C for $S \geq Q \geq R$

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